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Microgravity Research at LeRC

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MICROGRAVITY RESEARCH AT LeRC

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Abstract

The NASA Lewis Research Center is conducting a wide variety of ground-based science and microgravity flight experiments in the disciplines of fluid physics and transport phenomena, combustion science, and materials science. Extensive use is made of low-gravity ground-based facilities such as drop towers and a Learjet aircraft, as well as extensive normal-gravity laboratories. The ground-based facilities are utilized to execute science programs, perform precursor tests to define space experiment science requirements and conceptual designs, and also to perform tests for space experiment technology development and verification. Finally, flight hardware is designed, developed and flown on the Space Shuttle.

Introduction

The Lewis Research Center (LeRC) Microgravity Science and Applications (MSA) Program is an interdisciplinary effort to achieve a greater scientific understanding of the role of gravity in the fundamentals of microgravity science and materials processing. The field of microgravity is broad; it encompasses the physics and chemistry of a wide range of materials and processes, such as combustion, fluid physics, metals and alloys, glasses and ceramics, polymers, and electronic semiconductors.

The operations of the Space Transportation System (STS) afford to the scientific community unique opportunities to perform experiments in an environment that cannot be duplicated terrestrially (i.e., long-term low-gravity exposure). The on-orbit microgravity environment is characterized by greatly reduced buoyancy forces, hydrostatic pressure, and sedimentation. The LeRC MSA Program encourages and enables the scientist to utilize the potential of the STS and the future Space Station Freedom for carrying out research and value-added processing in space.

Extensive ground-based research must be conducted to define and support the microgravity science endeavors contemplated for space. System and experiment definition studies must be carried out to characterize the subject phenomena on the ground. A broad scientific and technical base has been developed by the LeRC MSA Program. Some knowledge of gravity-related effects is obtained by earth-bound, low-gravity experimentation that makes use of drop tower facilities or aircraft. Space-flight experiments are conducted to expand scientific understanding of the long-term effects.

The objectives of the NASA LeRC MSA Program are to: (1) Improve understanding of the role of gravity in the fundamentals of fluid physics, combustion science, and materials science and processing; (2) Develop joint NASA/university/industry involvement in cooperative scientific efforts; (3) Identify, justify, and define potential reduced gravity applications and concepts using earth-based or space facilities and conduct feasibility experiments; and, (4) Develop and conduct key in-space scientific experiments. The products of these endeavors are expected to be a combination of high quality science data and technology advancements related to both terrestrial- and space-based phenomena and processes.

The technical approach is to conduct both experimental and theoretical research on fundamental phenomena in order to define governing mechanisms, to validate models, and to obtain unique data that are free of the limiting and masking effects of gravity. A four-fold effort is employed to accomplish the objectives of this program: (1) A science experiment definition effort is done in collaboration with the academic and scientific communities; (2) Experimental and/or theoretical research projects are carried out in selected technical areas and utilize research laboratories and available ground-based, low-gravity facilities; (3) A dedicated interdisciplinary laboratory capability is established to permit ground-based experiments/procedures to be developed and verified prior to the development of flight hardware; and (4) Flight hardware is designed, fabricated, tested, qualified, and flown on the Space Shuttle, Spacelab, or Space Station Freedom.

Ground-Based Facilities

Ground-based facilities play a vital role in the microgravity science program because they provide the baseline, normal-gravity, and reduced-gravity data in support of both the ground and flight experiment programs. The facilities are utilized to execute complete ground-based science programs, perform precursor tests to define space experiment science requirements and conceptual designs, and also to perform tests for space experiment technology development and verification. The research performed in these facilities enhances the value and success of space experiments.

The Lewis Research Center operates a 2.2-Second Drop Tower, a 5-Second Zero-Gravity Facility, a Learjet aircraft, and a Microgravity Materials Science Laboratory (MMSL). The low-gravity research facilities utilize a free fall or semi-free fall condition for durations of 2 to 20 seconds at acceleration levels from 10^{-2} g (Learjet) to 10^{-6} g (Zero-Gravity Facility) in various combinations. Complementary drop tower and aircraft facilities are in use at the NASA George C. Marshall Space Flight Center (MSFC) in Huntsville, Alabama; the Jet Propulsion Laboratory (JPL) in Pasadena, California; and the NASA Lyndon B. Johnson Space Flight Center (JSC) in Houston, Texas.

The **2.2-Second Drop Tower** provides 2.2 seconds of low-gravity test time for experiment packages up to 125 kg of hardware weight by permitting the package to free fall a distance of 27 meters. Accelerations of less than 10^{-5} g are obtained during the fall as the experiment package falls freely within a drag shield. Data are normally acquired by high speed motion picture cameras and onboard data acquisition systems such as thermocouples, pressure transducers, and flow meters. The operating procedure is such that 8 to 12 tests can be performed in one day.

The 5.18-Second **Zero-Gravity Facility** with its 132 meter free fall distance in a vacuum drop chamber represents a significant expansion in experiment sophistication and research capabilities when compared to the 2.2-Second Drop Tower. Experiment hardware of up to 450 kg is mounted in a one meter diameter drop bus. The drop bus is enclosed in a protective cover and suspended over the chamber by a release mechanism. The chamber is evacuated to a pressure of 10^{-2} torr before the package is released. High speed motion picture cameras are employed to acquire data. Other data are either recorded onboard or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Normally, one test is performed per day.

Specially modified jet aircraft flying parabolic trajectories can provide significant increases in low-gravity experiment time when compared to drop towers but not without the penalty of higher gravity levels. For an experiment fixed to the body of an aircraft, accelerations in the range of 10^{-2} g can be obtained for up to 20 seconds. In larger aircraft, sufficient cabin volume allows certain experiments to be free-floated. This procedure generally produces accelerations below 10^{-3} g for a period of 5 to 10 seconds. LeRC maintains a **Learjet Model 25** aircraft which can be utilized for attached experiments only. Approximately 1.8 meters of cabin length are available for experiment mounting and researcher seating.

The **MMSL** provides opportunity for scientists and engineers from industry, university, or government agencies to explore potential low-gravity materials research concepts. It contains space-flight-type experimental equipment supplemented by appropriate materials characterization and computational facilities. Investigators are encouraged to take the first steps toward defining space flight experiments for later performance on the space shuttle or on the Space Station. The computational facilities may be used to model the expected fluid flow and heat transfer in microgravity experiments.

Research Topics

The LeRC MSA program consists of numerous activities in the disciplines of combustion science, fluid physics, and materials science. Research projects are conducted by researchers from university, industry, or government laboratories. Because of space limitations in this paper, only a partial listing of research projects will be given: See Tables 1 to 3. Full descriptions of the individual projects and research results can be obtained from the author or by consulting the publications listed in the Supplemental Material section of this paper.

In addition to the basic science programs listed above, the LeRC is conducting several advanced technology development projects in the areas of fluids and combustion diagnostics; high-temperature furnace technology; high-resolution, high-frame-rate video technology; vibration isolation technology; reactionless mechanisms and robotics; and laser light scattering instrument development. These projects are expected to provide advancements in technologies that will enable the development of future microgravity science experiment hardware and enhance the scientific integrity, sophistication, and quality of flight experiments.

Flight Experiments

As ground-based research proceeds to the point where the necessity for a long-time low-gravity environment is justified and defined, a flight experiment is initiated. The process is characterized by a series of science and engineering requirements and design and safety reviews. At the present time there are eight microgravity flight hardware projects under development by the Lewis Research Center and its associated science and engineering contractors.

The objective of the **Solid Surface Combustion Experiment (SSCE)** is to determine the mechanism of gas-phase flame spread over solid fuel surfaces in the absence of buoyancy-induced or externally imposed gas-phase flow. Photographic measurements in a low-gravity environment of flame shape and the rate of flame spread will be made. This data will provide insight into the relative importance of gas-phase momentum generated by vaporization/pyrolysis of the fuel surface and the diffusion of gas-phase fuel in controlling fuel/air mixing. Temperature measurements of both the fuel

Table 1. Microgravity Combustion Science Research

Solid Fuel Flame Spreading
- Solid Surface Combustion
- Forced Convective Flame Spread
- Smoldering Combustion
- Radiative Ignition
- Partial Gravity Flammability
- Flame Spread Modeling
- Turbulent Combustion
- Metals Combustion

Dispersed Heterogeneous Systems
- Particle Cloud Combustion

Premixed Gases
- Flammability Mechanisms
- Stabilized Cellular Flames
- Computational Modeling

Non-Premixed Gases
- Gas-Jet Diffusion Flames
- Burke-Schumann Flames

Pool Fires
- Ignition Susceptibility
- Flame Spreading
- Computational Modeling

Droplet Combustion
- Droplet Combustion
- Near-Critical Droplet Vaporization

Spacecraft Fire Safety
- Bibliography
- Space Station User's Study
- Fire Detection
- Fire Extinguishment

Table 2. Microgravity Fluid Physics Research

Capillary Phenomena
- Surface Tension Driven Flow
- Bubble/Droplet Dynamics
- Modeling of Coalescence
- Vapor Slug Migration
- Thermocapillary Convection
- Capillary Containment
- Benard Stability
- Capillary Convection
- Free Surface Phenomena
- Contact Angle Measurement
- Liquid in Rotating Tank
- Acoustic Forcing of Drops
- Surface Tension Studies

Phase Transitions
- Critical Fluid Light Scattering
- Critical Fluid Viscosity Measurement
- Critical Fluid Thermal Equilibration
- Pool Boiling
- Liquid Solid Phase Change
- Droplet Evaporation

Multiphase Flow
- Two-Phase Flow
- Flow Boiling
- Film Condensation

Multi-Component/Coupled Transport Flow
- Thermal/Double Diffusive Convection
- Mass Transport
- Thermoacoustic Convection

Dynamics of Solid-Fuel Interfaces
- Statistical Mechanics of Fluids
- Non-slip Condition

Magneto/Electrohydrodynamics
- Electrohydrodynamics

Nucleation and Cluster Phenomena
- Disorder-order Transitions

Table 3. Microgravity Materials Science Research

Metals and Alloys
- Isothermal Dendritic Growth
- Theory of Dendritic Growth
- Undercooling/Nucleation
- Macro-Microsegregation
- Sintering
- Channel Segregation

Glasses and Ceramics
- Combustion Synthesis
- Phase Separation
- Foaming in Glass
- Particle Sedimentation and Agglomeration

Computational Process Modeling
- Chemical Vapor Deposition
- Zone Melting
- Bridgman Growth
- Physical Vapor Transport
- Residual Acceleration Effects
- Process/Equipment Interactions

Electronic Materials
- GaAs Crystal Growth
- Physical Vapor Deposition
- Bridgman Growth
- Solution Crystal Growth

surface and the gas phase will provide an indication of forward heat conduction in both the solid and the vapor phases; it also will provide qualitative information on the radiant heat flux to and from the fuel surface. The initial experiment matrix is to be performed with thermally-thin paper samples. Subsequent experiments will use a thermally-thick polymethylmethacrylate sample. The SSCE is manifested on a number of Spacelabs (SLS-1 and USML-1) and in the middeck on several other shuttle flights.

The objective of the **Surface Tension Driven Convection Experiment** is to provide fundamental knowledge of thermocapillary flows, specifically, fluid motions generated by the surface-tractive force induced by the surface tension variation due to the temperature gradient along a free surface. Besides the scientific interest in these flows, there is technological importance in their application to materials processing in space, such as crystal growth and solidification. The dramatic improvements expected in space-processed materials may be limited by thermocapillary flows. Changes in the nature and extent of thermocapillary flows can cause deleterious fluid oscillations. Numerical modeling is not adequate to predict oscillations due to an inherent coupling among the imposed thermal signature, surface flow, and surface deformation. The flight experiment test matrix has been designed to verify the numerical model and to create and observe oscillations in flow. The test chamber, 10 cm in diameter and 5 cm deep, will be filled on-orbit with silicone oil. The design can provide either a flat or a curved free surface which can be centrally heated either externally by a CO_2 laser or internally by a resistance heater. The resulting thermocapillary flows are measured by particle image velocimetry that uses a laser light sheet to illuminate the test chamber cross section and an intensified video camera to record light scattered from micron-sized particles dispersed in the oil. Oil surface temperatures are measured with an IR scanning imager. The flight hardware is being designed for integration into a Spacelab double rack for an initial flight on the USML-1 mission.

The **Isothermal Dendritic Growth Experiment (IDGE)** is a basic materials science experiment that will test fundamental assumptions concerning dendritic solidification of molten metals and provide mathematical models describing important aspects of that process. Because virtually all industrial alloys solidify dendritically, correct models could lead to improved earth-based industrial production of alloys such as steel and aluminum. Specifically, the IDGE will provide precise quantitative data relating dendrite growth velocity, tip radius, and side branch spacing to melt supercooling, to material physical properties, and to acceleration (g levels). To permit direct visualization of dendritic growth, succinonitrile (SCN) will be used in the experiment. SCN is a transparent body centered cubic crystalline material that solidifies dendritically in a manner similar to iron. Subsequent to the space flights, the data will be used to test and correct previously developed mathematical models. The IDGE apparatus will be carried on a United States Microgravity Payload (USMP) carrier. It will automatically perform the same functions as manually operated ground-based apparatus. During flight, it will send data and slow-scan television images to earth. If required, the IDGE ground crew will be able to communicate commands to alter the apparatus programming.

Improving the homogeneity and purity of gallium arsenide are two major goals of current research by the GaAs crystal growth community. The objective of the **GaAs Crystal Growth Experiment** project is to define the magnitude of the effects of buoyancy-driven convection on the quality of melt-grown GaAs. This will be accomplished by conducting a comparative study of GaAs crystals grown from the melt with differing degrees of convective flow. The project involves the growth of GaAs crystals in one-G (maximum convection), in 1-g with an applied magnetic field (damped convection), and in microgravity aboard the Space Shuttle (minimum convection). All the space and ground-based growth experiments will be performed in a specially-designed growth ampoule and furnace system with an electronically-controlled gradient. Both doped and undoped GaAs will be grown. The distribution of the selenium dopant in the regrown crystals will be used to determine transport and segregation effects. The ground-based experiments will also examine the influence of convection on GaAs growth as a function of temperature gradient and magnetic field orientations. Interface demarcation will be used to characterize the shape of the liquid/solid interface. Semiconductor material characterization techniques will be utilized for detailed analysis of the earth and space-grown crystals. A numerical model of the fluid flow patterns in the melts will be constructed. The space-growth experiment will be flown in a Get-Away-Special canister. Two pre-grown boules of selenium-doped GaAs, 1 inch in diameter and 4 inches long, will be regrown during nominal 6-hour, low-g periods in the gradient furnaces. Power will be supplied by self-contained alkaline batteries. The temperature of the GaAs will be monitored at several locations. The cooling rate controlling the single crystal growth will be linearized by the microprocessor control system. Temperature, acceleration, and selected housekeeping data will be acquired and stored during the growth of each crystal.

The objective of the **Pool Boiling Experiment (PBE)** is to improve the understanding of the fundamental mechanisms that constitute nucleate pool boiling. The PBE will accomplish this by conducting experiments in microgravity and, coupled with appropriate analyses, will investigate the heat transfer and vapor bubble dynamics associated with nucleation, bubble growth/collapse, and subsequent motion. Interrelations among buoyancy, momentum, and surface tension, which govern the motion of the vapor and surrounding liquid, will be considered as a function of the heating rate at the heat transfer surface and the temperature level and distribution in the bulk liquid. The experiment is designed to fit into a Get-Away-Special canister. The flight experiment will be complemented by 1-g testing and limited 5-Second testing in the LeRC Zero-Gravity Facility.

The **Critical Fluid Light Scattering Experiment** will measure the decay rates and correlation lengths of density fluctuations in xenon at its critical density as a function of temperature. This will be achieved by using laser light scattering (correlation spectroscopy) and turbidity measurements. The goal of the experiment is to measure the fluctuation decay rate and correlation length at temperatures very near to the critical temperature. Such experiments are severely limited on earth because the gravitational field causes large density gradients in the sample due to the divergence of the compressibility of the gas as the critical temperature is approached. The experiment concept requires the automatic location, within 20 micro Kelvin, of the critical temperature of xenon at its critical density. Light transmission and fixed-angle scattering intensities will be measured at controlled temperatures, within 3 micro Kelvin, in the range 1 Kelvin to 100 micro Kelvin above the critical temperature. The control system will calculate and store the turbidity and correlation functions at each temperature. These data will be used during post-flight analysis to determine the density fluctuation decay rates and correlation lengths near the critical temperature. Critical parameters relating to optics geometry and alignment, sample cell design, temperature control, and sampling statistics have been successfully demonstrated in ground-based experiments. The flight experiment will utilize the USMP carrier for independent optics and electronics modules. The optics module will be vibrationally isolated and environmentally controlled and will include the laser source, photocell and photomultiplier detectors, sample cell and thermostat, and associated optics for making the required measurements. The electronics module will include the microprocessor control system, temperature control system, the photon correlator, and appropriate subsystems to provide for all the computation, communication, and data recording functions required by the experiment.

The **Critical Fluid Thermal Equilibration Experiment** will examine the thermal relaxation and the fluid density profile as a function of time after a temperature perturbation of sulfur hexafluoride near its liquid-vapor critical point. Past low-g, critical fluid experiments yielded unexpected results which were perhaps due to unanticipated time scales for relaxation dynamics. Future international experiments will depend on achieving thermal equilibrium to within a specified tolerance and on knowing how phases develop or disappear. This work is intended to determine the practical time scale needed to execute meaningful critical fluid space experiments and characterize the location and dynamics of density or phase domains within the critical sample. The experiment timeline allows observation of large phase domain homogenization without and with stirring right after thermostat installation in the European Space Agency's Critical Point Facility. Also observed will be the time evolution of heat and mass after a temperature step applied to a one-phase equilibrium sample, phase evolution and configuration upon going two-phase from a one-phase equilibrium, effects of stirring on a low-g two-phase configuration, and two-phase to one-phase healing dynamics starting from a two-phase low-g configuration. The results will quantify the mass and thermal homogenization time constant of a one-phase system under logarithmic temperature steps. During the full experiment, accelerometry, time correlated with the video records, will identify the compressible fluid dynamics associated with Shuttle acceleration events and provide the investigators with intuition about gravity effects in a non-vibration-isolated Shuttle environment. This experiment is manifested on the IML-1 Spacelab mission.

The primary objective of the **Space Acceleration Measurement System (SAMS)** is to provide an acceleration measurement and recording instrument capable of serving a wide variety of microgravity flight experiments. The instruments will be flown to acquire microgravity data at lower frequencies, wider band widths, broader dynamic range, and longer durations than have been previously achieved on the Shuttle. The design of the instrument takes into consideration requirements for space experiments located in the Shuttle Middeck, in the cargo bay, and in Spacelab. The two main components consist of remote triaxial sensor heads and a main unit. The main unit is comprised of a control panel, an electrical box, a support structure, and an optical disk digital memory system. The instrument design is modular and the design will facilitate technology updates of software and hardware. A data reduction software package will be developed and made available to users.

Supplemental Material

The NASA Microgravity Science and Applications Division has published several documents which describe the current program:

1. Microgravity Science and Applications Program Tasks, 1988 Revision, NASA Technical Memorandum 4097, January 1989.
2. Microgravity Science and Applications Apparatus and Facilities, January 1988.
3. Microgravity Science and Applications Bibliography: 1988 Revision - NASA Technical Memorandum 4098, January 1989; 1987 Revision - NASA Technical Memorandum 4067, September 1988; 1986 Revision - NASA Technical Memorandum 89608, January 1987.

Copies of these documents are available from the author or NASA Headquarters, Microgravity Science and Applications Division, Code EN, Washington, DC, 20546-0001.

The Lewis Research Center has published several documents which describe NASA's microgravity facilities and the Lewis ground-based and flight experiment programs in fluid physics, combustion science and materials science:

1. Lewis Research Center Microgravity Science and Applications Program Summary of Accomplishments - 1989; March 1990.
2. Jack Lekan, Microgravity Research in Ground-Based Facilities, NASA Technical Memorandum 101397, AIAA-89-0236, January 1989.
3. Jack A. Salzman, Microgravity Research Facilities at the NASA Lewis Research Center, International Symposium for Promoting Applications and Capabilities of the Space Environment, Tokyo, Japan, October 13-14, 1987.
4. Bruce N. Rosenthal *et al.*, Research Opportunities in Microgravity Science and Applications During Shuttle Hiatus, NASA Technical Memorandum 88964, April 1987.
5. Microgravity Combustion Science: A Program Overview, NASA Technical Memorandum 101424, January 1989.

Copies of these documents are available from the author.

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